Workshop ‘Spatio-temporal modeling for ecology’

Stream network activity

Some (bibliographic) context

Fisheries Research 259 (2023) 106583

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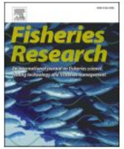

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Check for updates

Catchment-scale stream network spatio-temporal models, applied to the freshwater stages of a diadromous fish species, longfin eel (*Anguilla dieffenbachii*)

Anthony R. Charsley [a,*], Arnaud Grüss [a], James T. Thorson [b], Merrill B. Rudd [c], Shannan K. Crow [d], Bruno David [e], Erica K. Williams [a], Simon D. Hoyle [f]

Ecological Applications, 28(7), 2018, pp. 1782–1796

A geostatistical state-space model of animal densities for stream networks

Daniel J. Hocking,[1,4] James T. Thorson,[2] Kyle O'Neil,[3] and Benjamin H. Letcher[3]

[1]*Department of Biology, Frostburg State University, Frostburg, Maryland 21532 USA*
[2]*Fisheries Resource Analysis and Monitoring Division, Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, Washington 98112 USA*
[3]*Leetown Science Center, S.O. Conte Anadromous Fish Research Laboratory, U.S. Geological Survey, One Migratory Way, Turners Falls Massachusetts 01376 USA*

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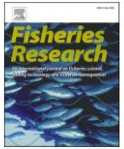

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A geostatistical state-space model of animal densities for stream networks

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Overall framework

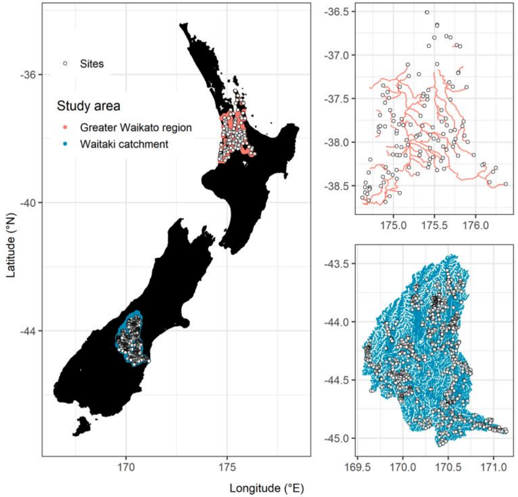
Case study: Longfin eel (Anguilla dieffenbachii), New Zealand

Ecological objective: estimating spatio-temporal changes in longfin eel populations in the freshwater environment

Data: Presence absence / Count data of eels, various fishing methods

+ Covariates (*e.g.* mean flow, distance to coast, mean elevation)

Statistical model: VAST + adaptation to stream network



Modeling framework | VAST

Category
(e.g. species)

Number of temporal effects

Number of spatial effects

Number of spatio-temporal effects

Linear
predictor for
observation i

$$p_1(i) = \underbrace{\mu_{\beta 1}(c_i) + \sum_{f=1}^{n_{\beta 1}} L_{\beta 1}(c_i,f)\ \beta_1(t_i,f)}_{\text{Temporal variation}} + \underbrace{\sum_{f=1}^{n_{\omega 1}} L_{\omega 1}(c_i,f)\ \omega_1(s_i,f)}_{\text{Spatial variation}} + \underbrace{\sum_{f=1}^{n_{\epsilon 1}} L_{\epsilon 1}(c_i,f)\ \epsilon_1(s_i,f,t_i)}_{\text{Spatio}-\text{temporal variation}}$$

$$+\underbrace{\sum_{p=1}^{n_p} \gamma_1(c_i,t_i,p) X(s_i,t_i,p)}_{\text{Habitat covariates}} + \underbrace{\sum_{k=1}^{n_k} \lambda_1(k)\ Q(i,k)}_{\text{catchability covariates}}$$

Number of habitat covariates

Number of catchability covariates

Modeling framework | VAST

Category
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$$+ \underbrace{\sum_{p=1}^{n_p} \gamma_1(c_i,t_i,p) X(s_i,t_i,p)}_{\text{Habitat covariates}} + \underbrace{\sum_{k=1}^{n_k} \lambda_1(k)\, Q(i,k)}_{\text{catchability covariates}}$$

Number of habitat covariates

Number of catchability covariates

Temporal, spatial and
spatio-temporal **random effects**

Modeling framework | VAST

Category (e.g. species)

Number of temporal effects

Number of spatial effects

Number of spatio-temporal effects

Linear predictor for observation i

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Number of habitat covariates

Number of catchability covariates

Loading terms

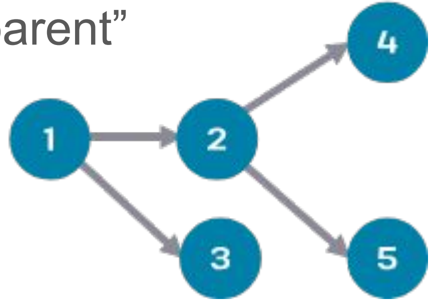
Relate the temporal, spatial and spatio-temporal effects to categories/species

Temporal, spatial and spatio-temporal **random effects**

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”



Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

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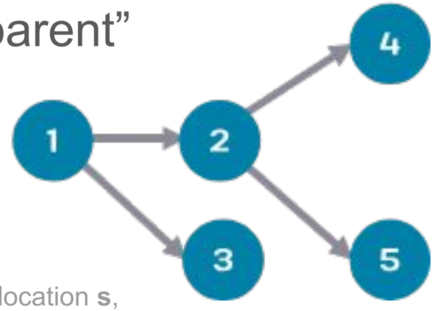


$$\omega(s)|\omega\left(s_{\{parent\}}\right) \sim Normal\left(\rho_s(s) \times \omega\left(s_{\{parent\}}\right), \sigma_s^2(s)\right)$$

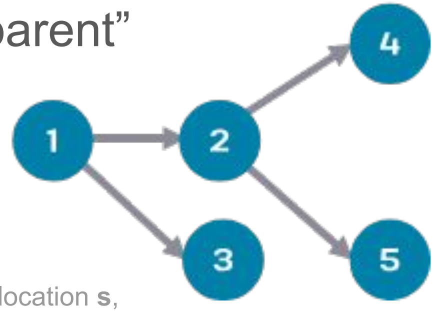
Expected spatial correlation between points in the stream network

Variance for spatial correlation for location **s**, conditioned upon the value for parent node $\mathbf{s}_{parent}$

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”



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Expected spatial correlation
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Variance for spatial correlation for location **s**,
conditioned upon the value for parent node $\mathbf{s}_{parent}$

$$\sigma_s^2(s) = \frac{\sigma_\tau^2}{2\theta_\tau}\left(1 - e^{-2\theta_\tau |s - s_{parent}|}\right)$$

Asymptotic variance for
two infinitely distant nodes

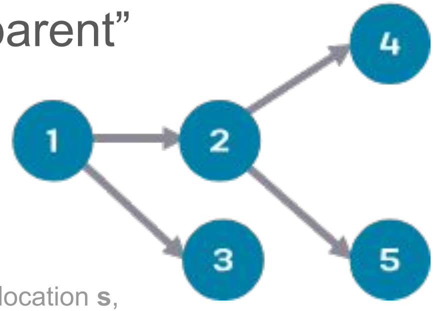
Exponential **rate of decorrelations**
between child and parent nodes,
⇒ Larger values represent faster decorrelation

Distance between location **s**
and parent node $\mathbf{s}_{parent}$

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”



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Expected spatial correlation between points in the stream network

Variance for spatial correlation for location **s**, conditioned upon the value for parent node $\mathbf{s}_{parent}$

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$$\sigma_s^2(s) = \frac{\sigma_\tau^2}{2\theta_\tau}\left(1 - e^{-2\theta_\tau |s - s_{parent}|}\right)$$

Asymptotic variance for two infinitely distant nodes

Distance between location **s** and parent node $\mathbf{s}_{parent}$

Exponential **rate of decorrelations** between child and parent nodes,
⇒ Larger values represent faster decorrelation

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”

Then define the **precision matrix**:

Exponential **rate of decorrelations**

$$Q_{stream}(s, s_{parent}) = Q_{stream}(s_{parent}, s) = \frac{-e^{-\theta_\tau |s - s_{parent}|}}{1 - e^{-2\theta_\tau |s - s_{parent}|}}$$

*Precision ⇒ represents the **conditional dependence** of child nodes given parent nodes*

Distance between location **s** and parent node $\mathbf{s}_{\mathbf{parent}}$

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”

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*Precision ⇒ represents the **conditional dependence** of child nodes given parent nodes*

Distance between location **s** and parent node $\mathbf{s_{parent}}$

Diagonal terms of the precision matrix

$$Q_{stream}(s, s) = 1 + \sum_{s' \in S} \frac{e^{-2\theta_\tau |s - s'|}}{1 - e^{-2\theta_\tau |s - s'|}}$$

Set of child and parent nodes that are **adjacent** to node **s**

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “c ... stream “parent”

Then define the **precision matri**

Markovian properties

Exponential **rate of decorrelations**

$$Q_{stream}(s, s_{parent}) = Q_{stream}(s_{parent}, s) = \frac{-e^{-\theta_\tau |s - s_{parent}|}}{1 - e^{-2\theta_\tau |s - s_{parent}|}}$$

Precision ⇒ repre ... e ***conditional dependence*** *of child ... odes given parent nodes*

Distance between location **s** and parent node $\mathbf{s}_{\mathbf{parent}}$

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Set of child and parent nodes that are **adjacent** to node **s**

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”

Then define the **precision matrix**.

Extension to time through a first-order autocorrelation process (not described here).

Modeling framework | Modelling spatio-temporal dependence

Ornstein-Uhlenbeck process

Define the acyclic graph of upstream “child” and downstream “parent”

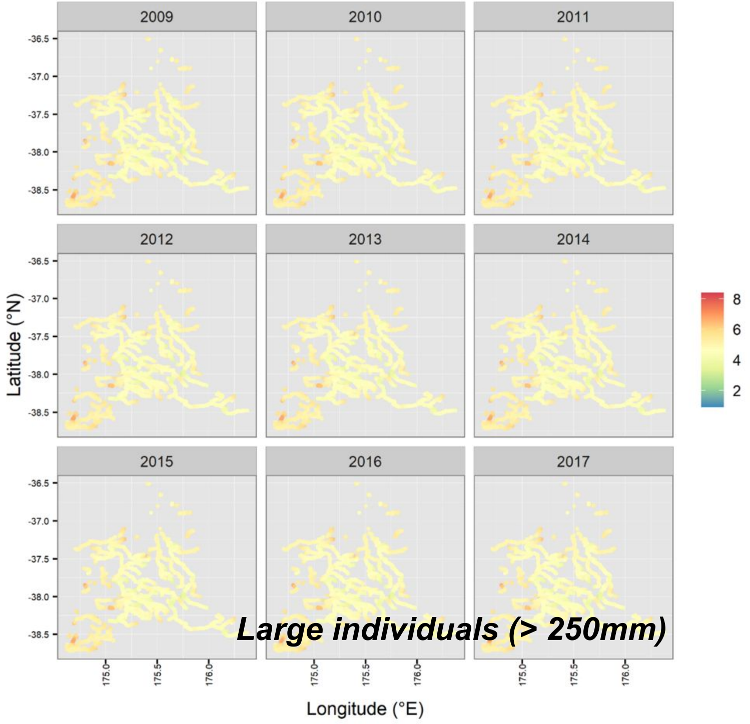
Then define the **precision matrix**.

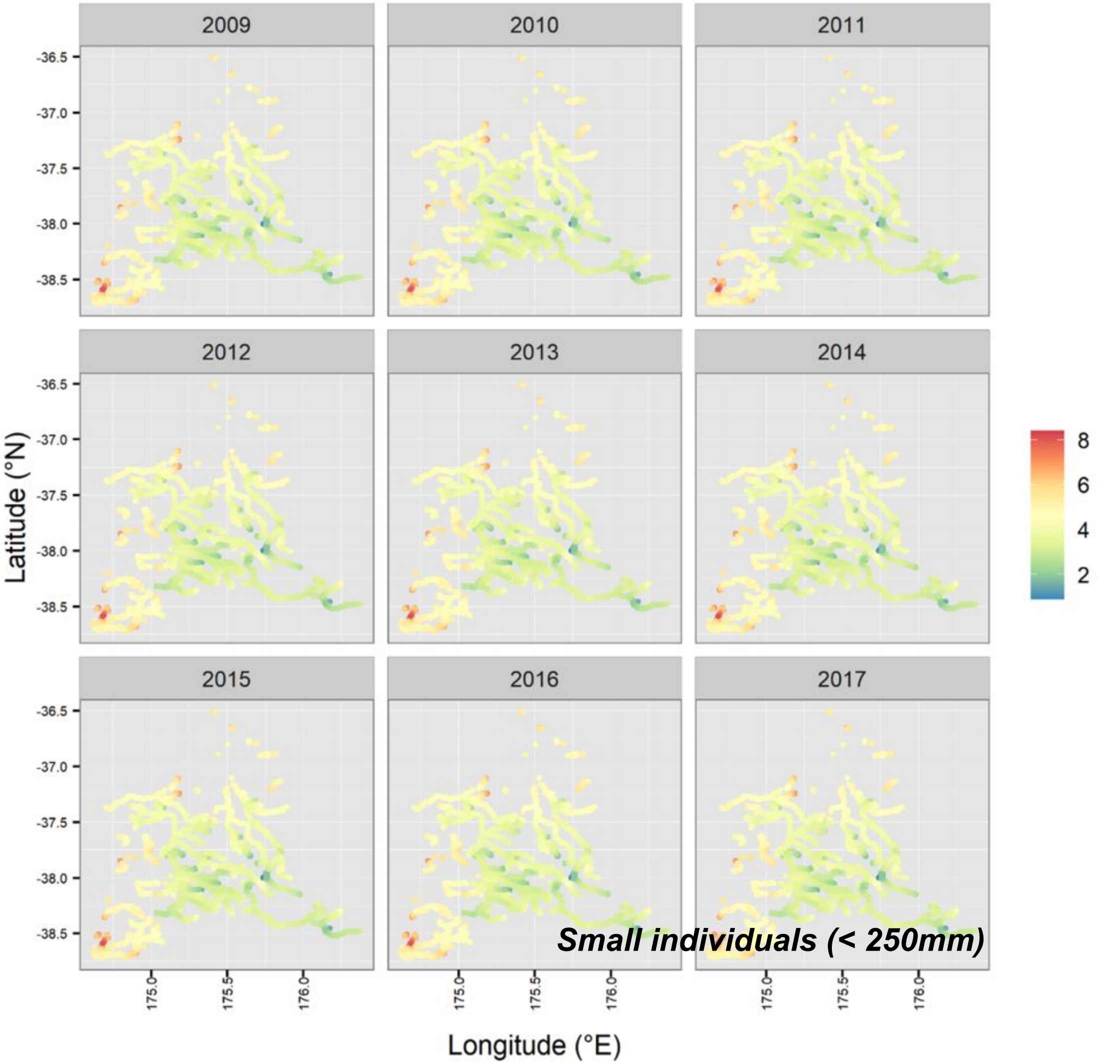
Extension to time through a first-order autocorrelation process (not described here).

Inference realized with TMB (standard for VAST/tinyVAST).

Some results

Map of predicted count/km





Our case study

Case study: Freshwater fish in the Loire River basin (France)

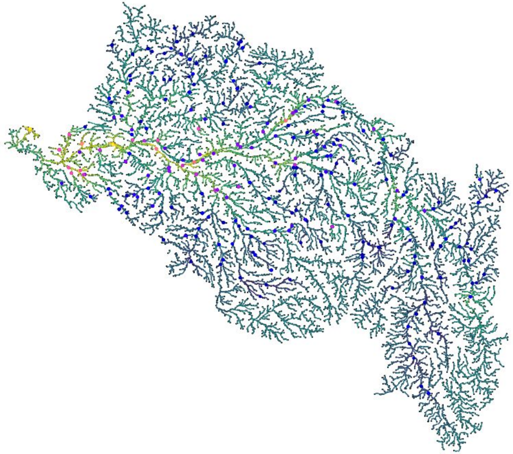
Ecological objective: Estimating spatio-temporal changes in fish populations in the freshwater environment

Data: Count data of freshwater fish in the Loire River bassin, 1990-2024 (ASPE database, OFB)

+ Covariates (*e.g.* distance to coast, elevation)

Statistical model: tinyVAST with adaptation to stream network

European eel spatial distribution in the Loire Bassin



Codes and questions to address

https://github.com/balglave/stream_sdm.git

Adding environmental covariates → need an interpolation step for prediction
Adding additional species (e.g. TRF – truite ; SPI – spirlin ; CHE – chevesne ;
CHA – chabot ; LOF – loche franche)
Checking the network
Other questions ?